Universidade De Lisboa
Faculdade de Motricidade Humana

The effects of the quantity of physical activity in cognition

Dissertação elaborada com vista à obtenção do Grau de Mestre em Exercício e Saúde

Orientador: Professor Doutor Duarte Araújo

Juri

Presidente: Doutor Duarte Fernando da Rosa Patronilho Araújo

Vogais: Doutor Paulo Alexandre Silva Armada da Silva;

Doutora Ana Maria Blom Vidal Abreu

João Paulo Gomes Susano

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Abstract

Exercise promotes the increase of cognitive performance (Aberg et al., 2009), however, the quantity of physical activity needed to achieve this effect is not clearly defined. The present study aimed to research the effects of the quantity of physical activity practice on the executive function of healthy adults, measured by performance on the Stroop test. Results showed that the sedentary group had a worst performance than both groups of physically active individuals. Interestingly, this positive effect of exercise on cognitive performance did not increase with the increase in the quantity of physical activity practiced by the individuals. In conclusion, a moderate quantity of practice (150 min per week) produces the highest amount of benefits for cognitive performance, in comparison with a high quantity of practice (300 min per week).

Keywords: cognition, exercise, sedentary, cognitive evaluation, cognitive performance, executive function, exercise quantity, Stroop Test.

Introduction

Exercise behavior is gradually becoming part of people's life not just for aesthetic reasons but also for well-being, productivity, and health related-reasons. In fact, it is well documented the benefits of exercise. Some of the most recent findings of exercise benefits are related to cognitive performance. These findings reveal an increase in the performance of several cognitive functions with exercise practice. Such results are important for brain dysfunction and disease therapy, recovery and prevention especially in adults and elders, but also for the cognitive development of children, adolescents and young adults. However, some questions remain considering the effects of chronic exercise, (i) what are the differences in the cognitive effects derived from the quantity of exercise practiced? (ii) what is the minimum amount of exercise practice necessary for improving cognitive performance?

Addressing the aforementioned questions, we now present a brief review of literature focusing on the existing research that is related with the aim of this study.

Exercise and Cognition

Recently, there has been an increase in studies researching the effects of physical activity on cognition (Aberg, Pedersen, Torén, Svartengren, Backstrand, Johnsson, Cooper-Kuhn, Aberg, Nilsson & Kuhn, 2009). These effects may be seen at the systemic, molecular, and cellular levels (Ratey & Loehr, 2011). At the systems level, physical activity is responsible for increased performances on executive function (Best, 2010; Davis, Tomporowski, McDowell, Austin, Miller, Yanasak, Allison & Naglieri, 2011), attention and memory (Budde, Voelcker-Rehage, PietraByk-Kendziorra, Ribeiro, & Tidow, 2008; Chaddock, Erickson, Prakash, Kim, Voss, VanPatter, Pontifex, Raine, Konkel, Hillman, Cohen & Kramer, 2010; Chaddock, Hillman, Buck, & Cohen, 2011) and learning reflected mainly on school achievement (Carlson, Fulton, Lee, Maynard, Brown, Kohl & Dietz, 2008; Castelli, Hillman, Buck, & Erwin, 2007; Chomitz, Slining, McGowan, Mitchell, Dawson & Hacker, 2008; Coe, Pivarnik, Womack, Reeves, & Malina, 2006). Studies using P300 – a positive-going waveform that peaks approximately 300-800 ms after stimulus onset, reflecting neural activity underlying basic cognitive functions such as attentional resource allocation (Hillman, Pontifex, & Themanson, 2009) – showed that exercise increases the allocation of attention and memory resources at the neuroelectric level (Hillman et al., 2009; Ratey & Loehr, 2011) . Neuroimaging studies support and extend the findings that exercise affects brain structure, by demonstrating changes in brain function/activity after participating in a regimen of physical exercise (Ratey & Loehr, 2011). Also, physical activity influences the decreasing of pathological cognitive degeneration due to the aging process (Nouchi, Taki, Takeuchi, Hashizume, Nozawa, Sekiguchi, Nouchi & Kawashima, 2012; Pedrovan, Fraser, Renaud, & Bherer, 2012).

At the molecular level, physical activity increases the availability of neurotrophins (BDNF) and growth factors (IGF-1) in the brain (Ratey & Loehr, 2011). Finally, at the cellular level, the signaling cascades induced by neurotrophins and growth factors regulate cellular effects that support brain function, including synaptic plasticity, neurogenesis, and angiogenesis (Ratey & Loehr, 2011).

The vast majority of exercise and cognition studies focus on the relation between sporadic doses of exercise that vary in intensity and their effects on cognition. Little is known about the relation between the quantity of accumulated exercise over time and its effects on cognitive performance. Davis et al (2011) revealed that a daily intervention of 40 minutes of exercise promotes better cognitive performances than a daily intervention of 20 minutes. An intervention of exercise once a week revealed no effect on cognitive performance in children (Liu-Ambrose, Nagamatsu, Voss, Khan, & Handy, 2012), Importantly, Colcombe and

Kramer (2003) showed that at least 30 min of exercise two to three times per week have positive effects on cognitive performance. But the literature do not clarify if the effects of exercise on cognitive performance would be higher when comparing individuals who practice at least the minimum quantity to be considered physically active - 150 min per week of moderate intensity physical activity (ACSM, 2011) – and the individuals who largely exceed that quantity of practice (e.g., 300 per week). Importantly, the definition of cognition needs to be clarified, namely by addressing what is known as executive function.

Executive Function

The executive function is defined as a set of mental processes responsible for decision making, objective planning and behavior choice (McMorris, Tomporowski, & Audiffren, 2009). Although the characteristics of the executive function are still in debate, there is a general consensus among researchers that it shouldn't be defined as an unitary process. The main consensus is that executive function is a complex set of processes based on: i) inhibition, which refers to inhibitory control and includes the auto-control (behavioral inhibition) and the interference control (selective attention and cognitive inhibition); ii) working memory that implies the involving perception of the display, holds the necessary information in short-term memory, compares the present situation with similar past experiences held in long-term memory and, from this comparison, makes a decision (Baddeley, 1986); and iii) mental flexibility that is the capacity of being able to change perspectives spatially or interpersonally (Diamond, 2013). This is the base for other processes like planning, problem solving and reasoning (Collins & Koechlin, 2012; Lunt, Bramham, Morris, Bullock, Selway, Xenitidis & David, 2012). The executive functions are essential for the mental and physical health, success in school and in life and for a proper psychological, social and cognitive development (Diamond, 2013).

The inhibitory control involves being able to control attention, behavior, thoughts, and/or emotions to override a strong predisposition or external lure and instead do what is more appropriated or needed (Diamond, 2013). The inhibitory control of attention (interference control at the level of perception) enables the individuals to select the focus of the attention on what they choose, suppressing the attention to every other stimuli (Diamond, 2013). Another type of interference control is the suppression of motor responses and memories (Diamond, 2013).

The response time plays an important role on inhibitory control. According to Simpson and Riggs (2007), increasing the response time precipitate the predominant response until it reaches the response borderline and then, starts to weaken the correct answer (that is not predominant) (Diamond, 2013). Thus, the less available time between the stimuli and the response, the bigger the tendency for giving the prepotent response instead of the correct one.

The inhibitory control is disproportionally difficult for children (Diamond, 2013) making them more impulsive, and this tendency increases during adolescence (Luna, 2009). Above the age of 60, the inhibitory control suffers a noticeable decline (Hasher, Stoltzfus, Zacks, & Rypma, 1991; Hasher & Zacks, 1988).

A recent review found evidences demonstrating that prolonged physical activity interventions have consistent effects in the performance of tasks that require the use of the inhibition and coordination capacities, compared with tasks that require the use of attention shifting capacity[1], suggesting that the executive function could be selectively affected by physical exercise (Barenberg, Barse, & Dutke, 2011). A recent study realized by Tam (2013) conclude lso that physical exercise promote immediate responses (acute) on executive function level, increasing the inhibition capacity (Tam, 2013). Tam's study used a digital version of the Stroop Color-Word Test and the results showed that after a bout of less than 30

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[1] The capacity to change attention focus from one task/subject to another.

minutes of cardiovascular exercise, the processing speed of the executive function increased and the error rate decreased. This has been observed in both the congruent and incongruent versions of the test suggesting that cardiovascular exercise has an immediately effect on improving the executive function as measured by the Stroop Tests (Tam, 2013). Therefore the measurement of cognition, specially in relation with exercise needs to be clarified.

Exercise and Cognitive evaluation

The evaluation of the relationship between exercise and cognition has several limitations. McMorris et al. (2009) refers that an operational definition of the cognitive constructs must be established for the measurement to be objective and quantifiable. Constructs defined operationally facilitate communication among researchers by reducing or eliminating misinterpretations. Although exercise constructs are well defined (e.g. Intensity, Volume and Time), psychological constructs are mostly abstract and there is a lack of agreement concerning the operational definitions of the cognitive constructs used by researchers (McMorris et al., 2009). Psychological tests were developed in order to link the abstract concepts used to explain causal relations between natural events, to a set of procedures that are used to measure real-world events (McMorris et al., 2009). Attention, executive function and memory are the most widely used constructs on the effects of exercise on cognition research since they're the main constructs at the systems level affected by exercise practice (Ratey & Loehr, 2011). Both electrocortical activity and neuroimaging studies showed that exercise influence cognitive performance mostly through attentional mechanisms (Colcombe, Kramer, Erikson, Scalf, McAuley & Cohen, 2004; Hillman et al., 2009; Hilman, Kramer, Belopolsky, & Smith, 2006; Kamijo & Takeda, 2010; Polich & Lardon, 1997). Cognitive psychologists have developed a number of tasks designed to access specific types of attentional processing (McMorris et al., 2009) being the Stroop task one of the most widely used when studying the relationship between exercise and cognition (Buck, Hillman, & Castelli, 2007; Predovan, Fraser, Renaud, & Bherer, 2012; Tam, 2013; Vasques, Moraes, Silveira, Deslandes, & Laks, 2011).

The Stroop Test

The Stroop task is a well known paradigm of cognitive psychology and also one of the most used contributions for clinical psychology (MacLeod, 2005). In one of his experiments, John Stroop (1935) observed a dramatic increase in the necessary time to identify colors by their name, when they were displayed in an incongruent form between the word naming a color and the color in which the word was written, giving place to what would be called the “Stroop Effect”. The shorter response time is the word reading, in comparison with naming the word font color (MacLeod, 2005). When there is an interference of stimuli and they are incongruent (e.g. a word with a different meaning of the figure that it represents), the response tends to take longer and increase the number of errors. In the Stroop Test, the task is to name the word font color, and not to read the word. The capacity to do this process in the shortest time and with the minimum of errors reflects the inhibition and shifting cognitive capacities of the executive function (Tam, 2013).

Previous research demonstrates that performance on the Stroop Test is not influenced by gender, but it changes with age (MacLeod, 1991). MacLeod refers that the interference effect begins in the first years of school and increases until the 4th and 5th year of school. At this moment the interference reaches its maximum influence due to the reading practice. Then the interference starts to decrease until the age of 60, and it increases again after this age (MacLeod, 1991).

The Stroop Test consists in presenting a sequence of cards with 20 rectangles. Each rectangle has written the name of a color, but the word font color is incongruent with its meaning (e.g., green written in red font). The task is to identify the color in which the word was written as quickly as possible. Nowadays, with the advance in the computer technology, most of the Stroop Tests are made digitally using the same principle of the card version. Digitally, the identification of the colors can be either manual, by clicking with the mouse on an option available; or verbal, by telling to the researcher the respective color (MacLeod, 2005).

There are online versions the Stroop Test already available and being utilized in research (Schubert, Murteira, Collins, & Lopes, 2013). Using a web-based Stroop test allows for a dramatic increase in the sample dimension and also for an increase in the spectrum of possible demographic variables that can be obtained on our sample, and possibly offering a better representation of the population (Gosling, Vazire, Srivastava, & John, 2004; Skitka & Sargis, 2006). An online test turns the recruitment process significantly easier, less expensive, and less time consuming, in comparison to the personal individual recruitment process (Gosling et al., 2004). From a theoretical point of view, this may be a first step to a mode detailed analysis of the mechanisms that allow physical activity to influence cognitive performance.

Objectives of the study

Following this theoretic rationale, the main objective of the study was to assess the effects of the quantity of exercise on cognitive performance, as measured by the Stroop test.

Methods

Participants

174 participants (108 males, 66 females, M_{age} = 27.37, SD =± 8.44 years, age range: 13-53 years) were recruited through e-mail, Facebook publications and personal contacts. Other participants were excluded from the study because one of these reasons: (i) they did not complete the full test, (ii) they failed the test due to errors on the platform (e.g. tests with 10 presentations and a registry of 13 correct answers and 7 wrong answers), (iii) they were under 12 years old due to negative effects of inexperienced readers on the Stroop Test (MacLeod, 1991), (iv) they don't have normal or corrected to normal visual acuity and (v) they exceed the 40 seconds of test time (time in which it was observed a discrepancy on the results due to the interference effect cessation).

The sample was divided in 3 different groups according to their physical activity level: sedentary (less than 150 min per week of PA practice)(N = 53, M_{age} = 30.02, SD = 1.06 years, M_{PAtime}= 35.28, SD = 7.11 min), moderate PA (150 to 299 min per week of PA practice)(N = 51, M_{age} = 27.86, SD = 1.27 years, M_{PAtime} = 207.41, SD = 6.67 min) and intense PA (300 min and above per week of PA practice)(N = 70, M_{age} = 26.12, SD = 0.883 years, M_{PAtime} = 567.70, SD = 41.23 min).

In order to control confounding variables, the sample was also previously divided by gender (2 groups – Male; Female) and education level (3 groups – Basic; Secondary; Academic) (see Table 1 for PA level distribution).

Table 1

Description of the experimental groups by gender, age and education level.

PA Level	Gender *N*		Education Level *N*		
	Male	Female	Basic	Secondary	Academic
Sedentary	28	28	1	11	44
Moderate PA	33	15	2	13	33
Intense PA	47	23	5	15	50

Study design

A web-based version of the Stroop Test was used in this study using two similar platforms (www.messtrooptest.co.nf and www.MenPas.com). The test consisted in the presentation of a line of 13 rectangles with 1.8 cm width and 1.3 cm height, displayed side by side and each one filled with a different background color. On the top of the rectangles line there's another rectangle with 5.29 cm width and 3.47 cm height, filled with a neutral background color different from white and from the other 13 colors presented on the 13 rectangles in the line. This background color should permit an easy reading of any word written in any of the 13 other colors. Inside this rectangle is a word that names one of the 13 colors presented on the 13 rectangles in the line. That word is always written in a color different from its meaning (e.g. the word "blue" written in yellow letters), and both the meaning and the written color are randomly presented. The objective of the test is to choose the font color – the color in which the word is written - of the presented word by clicking on the rectangle with the respective background color.

Prior to the presentation of the test there was a form and the test instructions. The participant fulfilled his/her age, gender, height, weight, education level (for confounding variables control), the selection between sedentary or physically active following the ACSM guidelines standards (ACSM, 2011) , number of hours of physical activity (PA) practiced per day (if applicable), number of days of PA per week (if applicable)(for calculation of the independent variable – number of days per week x number of hours of PA practice per day), since when is the person physically active (if applicable), and what sport the participant practiced if any. After the fulfillment of the form, the instructions of the test were presented with text and images. As part of the instructions, participants were informed that they should do the test as quickly as possible and in a quiet and lonely environment. There was no explicit time limit, but participants were excluded if they took more than 40s. The test ends after 10 presentations of different words with different meanings and font colors. At the end of the test, the results (total test time, correct answers and wrong answers) are displayed as a feedback for the participant.

These data were saved on a SQL database in a designated server. In addition to the form data, the date and hour of the test, and the IP of the participant were saved on the database, to identify repeated tests from the same participant. Only the first attempt of every participant was considered.

The Stroop test results were computed as it is traditionally proposed (Stroop, 1935): (i) the final time was divided by the number of presentations – ten – resulting in a mean partial time, then, (ii) the wrong answers were converted in additional time, in amounts proportional to the partial time, and as many as the number of wrong answers, and (iii) this additional time obtained from the wrong answers was added to the final time. This compound variable considered simultaneously the relationship between the accuracy and the response time. This measure of the cognitive performance as indicated by the “overall time” of the Stroop test was the dependent variable. Therefore a One-Way ANOVA was employed, with alpha at the 5%, and a one-tail test.

In order to control the confounding variables gender and education level, 2 One-Way ANOVA tests were made for comparing gender (male and female), education level (Basic, College and University degree) of the whole sample.

According to McLeod (1991) the Stroop effect changes with age until 12 years old and above 60 years old. Since the sample age range was from 13 to 53 years old, age was not considered a confounding variable.

Results

Control of the confounding variables

The One-Way ANOVA showed no differences between the confounding variable groups Gender $F(1, 172) = 0.285$, $p = .60$, $\eta^2 = 0.002$ and Education Level $F(2, 171) = 0.745$, $p = .47$, $\eta^2 = 0.009$.

The effects of Physical Activity on the Stroop test results

For the One-way ANOVA test a Levene's test for homogeneity of Variances was employed indicating that there was homogeneity of variances for the variables in study ($p = .643$).

The One-Way ANOVA results were significant for the difference between the Physical Activity Level groups $F(2,171) = 5.60$, $p = .004$, $\eta^2_{\text{part}} = .062$ showing a reduction in the overall time of the Moderate PA group ($p = .012$) and the Intense PA group ($p = .010$) when compared with the Sedentary group (see Table 1 for descriptive statistics). No differences were found between the Moderate PA group and the Intense PA group (Figure 1).

Table 2

Descriptive statistics of PA Level groups (i) Sedentary (<150 min PA/week), (ii) Moderate PA (150 min – 300 min PA/week), (iii) Intense PA (> 300 min PA/week).

PA Level	*N*	*Mean* Final Time (s)	SD
Sedentary	53	21.46	5.53
Moderate PA	51	18.46	5.38
Intense PA	70	18.59	5.08

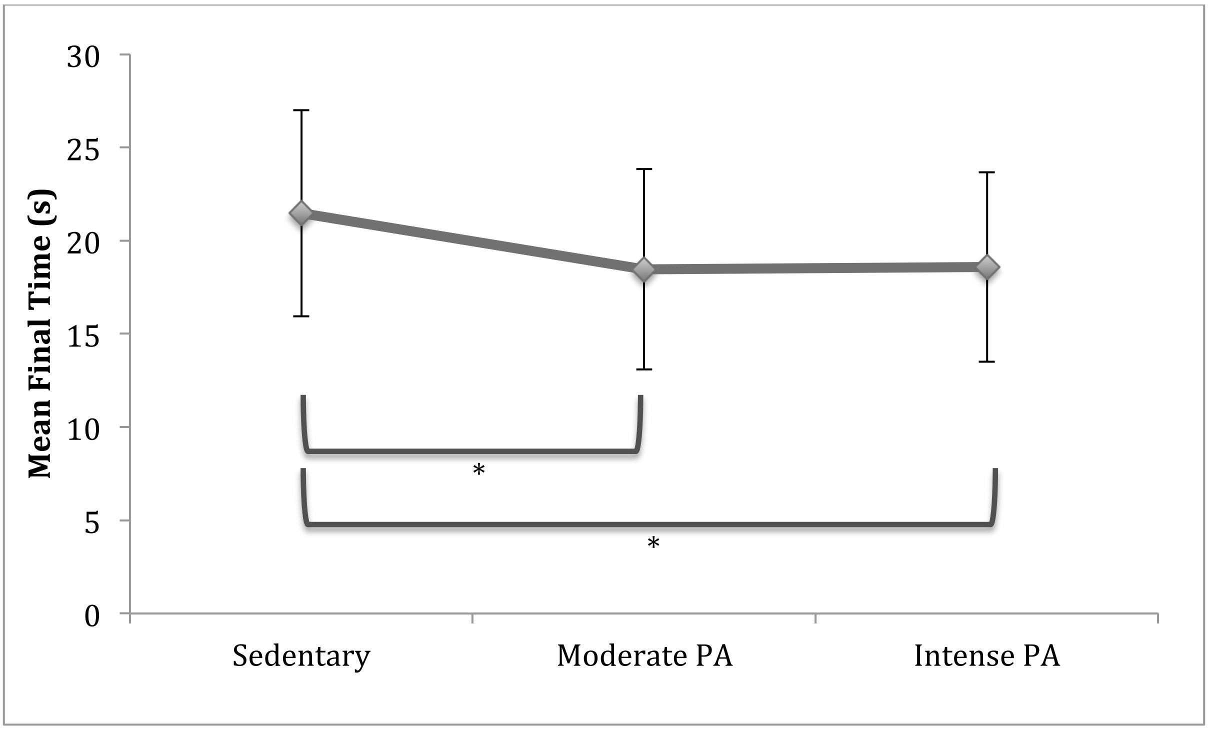

Figure 1 – Mean Final Time for the three groups of physical activities. Error bars represent the standard deviations.

In Figure 1, Tukey HSD Post-Hoc test showed differences between the Sedentary and the Moderate PA groups (p = .012) and the Sedentary and Intense PA groups (p = .010); there were no differences between the Moderate and the Intense PA groups (p = .990) at a significant level of 0.05.

Discussion

The objective of the study was to verify the effects of the quantity of exercise on the cognitive performance. The results obtained support the existence of positive effects of exercise on cognitive performance. However, differences were observed only between the Sedentary and both Moderate PA (p = .012) and Intense PA (p = .010) groups, and not between Moderate PA and Intense PA groups.

These results suggest that a minimum of 150 min of physical activity per week - the threshold between sedentary and physically active individuals according to ACSM (2011) - may be sufficient for improving cognitive performance. These results corroborate previous studies with P300 analysis of electrocortical activity it was observed that bouts of a minimum of 18 min of exercise decreases P300 latency decreasing reaction time and increasing the P300 amplitude, indicating a decrease in the amount of resources necessary to produce a response (Hillman, Snook, & Jerome, 2003; Kamijo, Nishihira, Hatta, Kaneda, Wasaka, Kida & Kuroiwa, 2004)

It seems that increasing the amount of exercise practice doesn’t produce significant changes on cognitive performance. These results are aligned with Erickson et al. (2010) who suggests that although there’s a critical threshold of physical activity that has to be reached during middle adulthood to reveal positive effects on brain structure, performing more physical activity do no lead to additional brain volume gains.

In practical terms, these findings can represent a step further in a better exercise prescription for the cognitive development, rehabilitation and disease/deterioration prevention. Shift the focus from the increase in quantity beyond the 150 min per week, to the quality and type of exercise is a way to promote the lifelong exercise practice. The majority of the drop offs is due to the lack of time for exercise practice, and the lack of motivation for high exercise exertion. Thirty minutes of exercise practice per day is easily manageable with all other daily activities. However, further research is needed to access the validity of other cognitive evaluation instruments (e.g. Flanker Test) in order to make a more solid cognitive evaluation.

In conclusion, the quantity of exercise is an important facto to consider for obtaining cognitive performance gains. It seems that 150 min per week is enough to favor an healthy cognitive development.

Bibliography

Aberg, M. A. I., Pedersen, N. L., Torén, K., Svartengren, M., Backstrand, B., Johnsson, T., . . . Kuhn, H. G. (2009). Cardiovascular fitness is associated with cognition in adulthood. *PNAS, 106*(49), 20906-20911.

ACSM. (2011). Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory, Musculoskeletal, and Neuromotor Fitness in Apparently Healthy Adults: Guidance for Prescribing Exercise. [Press release]

Baddeley, A. (1986). *Working Memory*, Oxford University Press, New York.

Barenberg, J., Barse, T., & Dutke, S. (2011). Executive Functions in learning processes: do they benefit from physical activity? *Educational Research Review, 6*(3), 208-222.

Best, J. R. (2010). Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. *Developmental Review*(30), 331-351.

Buck, S. M., Hillman, C. H., & Castelli, D. M. (2007). The Relation of Aerobic Fitness to Stroop Task Performance in Preadolescent Children. *Medicine & Science in Sports & Exercise*, 166-172.

Budde, H., Voelcker-Rehage, C., PietraByk-Kendziorra, S., Ribeiro, P., & Tidow, G. (2008). Acute coordinative exercise improves attentional performance in adolescents. *Neuroscience Letters*(441), 219-223.

Carlson, S. A., Fulton, J. E., Lee, S. M., Maynard, L. M., Brown, D. R., Kohl, H. W., & Dietz, W. H. (2008). Physical Education and Academic Achievement in Elementary School: Data from the Early Childhood longitudinal Study. *American Journal of Public Health, 98*(4), 721-727.

Castelli, D. M., Hillman, C. H., Buck, S. M., & Erwin, H. E. (2007). Physical Fitness and Academic Achievement in Third- and Fifth-Grade Studens. *Journal of Sport & Exercise Psychology*(29), 239-252.

Chaddock, L., Erickson, K. I., Prakash, R. S., Kim, J. S., Voss, M. W., VanPatter, M., . . . Kramer, A. F. (2010). A neuroimaging investigation of the association between aerobic fitness, hippocampal volume, and memory performance in preadolescent children. Retrieved 20 November 2013

Chaddock, L., Hillman, C. H., Buck, S. M., & Cohen, N. J. (2011). Aerobic Fitness and Executive Control of Relational Memory in Preadolescent Children. *Medicine & Science in Sports & Exercise, 43*(2), 344-349.

Chomitz, V. R., Slining, M. M., McGowan, R. J., Mitchell, S. E., Dawson, G. F., & Hacker, K. A. (2008). Is There a Relationship Between Physical Fitness and Academic Achievement? Positive Results From Public School Children in the Northeastern United States. *Journal of School Health, 79*(1), 30-37.

Coe, D. P., Pivarnik, J. M., Womack, C. J., Reeves, M. J., & Malina, R. M. (2006). Effects of physical Education and Activity Levels on Academic Achievement in Children. *Medicine & Science in Sports & Exercise, 38*(8), 1515-1519.

Colcombe, S. J., Kramer, A. F., Erikson, K. I., Scalf, P., E.McAuley, & Cohen, N. J. (2004). Cardiovascular fitness, cortical, plasticity, and aging humans. *Proc. Natl. Acad. Sci. USA, 101*, 3316-3321.

Collins, A., & Koechlin, E. (2012). Reasoning, learning and creativity: frontal lobe function and human decision-making. *PLoS Biol.*, 10:e1001293.

Davis, C. L., Tomporowski, P. D., McDowell, J. E., Austin, B. P., Miller, P. H., Yanasak, N. E., . . . Naglieri, J. A. (2011). Exercise Improves Executive Function and Achievement

and Alters Brain Activation in Overweight Children: A Randomized, Controlled Trial. *American Psychological Association, 30*(1), 91-98.
Diamond, A. (2013). Executive Functions. *Annual Review of Psychology*(64), 135-168.
Gosling, S. D., Vazire, S., Srivastava, S., & John, O. P. (2004). Should We Trust Web-Based Studies? A Comparative Analysis of Six Preconceptions About Internet Questionnaires. *American Psychologist, 59*(2), 93-104.
Hasher, L., Stoltzfus, E., Zacks, R., & Rypma, B. (1991). Age and inhibition. *Journal of Experimental Psychology*(17), 163-169.
Hasher, L., & Zacks, R. (1988). Working memory, comprehension, and agind: a review and a new view. In G. Bower (Ed.), *The Psychology of Learning and Motivation: Advances in Research and Theory*. San Diego CA: Academic.
Hillman, C. H., Snook, E. M., & Jerome, G. J. (2003). Acute Cardiovascular exercise and executive control function. *International Journal of Psychophysiology, 48*, 307-314.
Hillman, C. H., Pontifex, M., & Themanson, J. R. (2009). Acute aerobic exercise effects on event-related brain potentials. In T. McMorris, P. Tomporowski & M. Audiffren (Eds.), *Exercise and Cognitive Function* (pp. 161-178): John Wiley & Sons, Ltd.
Hilman, C. H., Kramer, A. F., Belopolsky, A. V., & Smith, D. P. (2006). A cross-sectional examination of age and physical activity on performance and event-related brain potentials in a task switching paradigm. *Int. J. Psychophysiology, 59*, 30-39.
Kamijo, K., Nishihira, Y., Hatta, A., Kaneda, T., Wasaka, T., Kida, T., & K.Kuroiwa. (2004). Differential influences of exercise intensity on information processing in the central nervous system. *European Journal of Applied Physiology, 92*, 305-311.
Kamijo, K., & Takeda, Y. (2010). Regular physical activity improves executive function during task switching in young adults. *Int. J. Psychophysiology, 75*, 304-311.
Liu-Ambrose, T., Nagamatsu, L. S., Voss, M. W., Khan, K. M., & Handy, T. C. (2012). Resistance training and functional plasticy of th aging brain: a 12-month randomized controlled trial. *Neurobiology of Aging, 33*, 1690-1698.
Luna, B. (2009). Developmental changes in cognitive control through adolescence. *Adv. Child Dev. Behav.*(37), 233-278.
Lunt, L., Bramham, J., Morris, R., Bullock, P., Selway, R., Xenitidis, K., & David, A. (2012). Prefrontal cortex dysfunction and "Jumping to Conclusions": bias or deficit? *Journal of Neuropsychology*(6), 65-78.
MacLeod, C. M. (1991). Half a Century of Research on the Stroop Effect: An Integrative Review. *Psychological Bulletin, 109*(2), 163-203.
MacLeod, C. M. (2005). The Stroop Task in Cognitive Research. In A. Wenzel & D. C. Rubin (Eds.), *Cognitive methods and their application to clinical research* (Vol. ix, pp. 17-40). Washington, DC, US: American Psychological Association.
McMorris, T., Tomporowski, P., & Audiffren, M. (2009). *Exercise and Cognitive Function* (1st ed.). West Sussex, UK: Wiley-Blackwell.
Nouchi, R., Taki, Y., Takeuchi, H., Hashizume, H., Nozawa, T., Sekiguchi, A., . . . Kawashima, R. (2012). Beneficial effects of short-term combination exercise training on diverse cognitive functions in heathy older people: study protocolo for a randomized controlled trial. *Trials,* (13). Retrieved from trialsjournal website:
Pedrovan, D., Fraser, S. A., Renaud, M., & Bherer, L. (2012). The Effect of Three Months of Aerobic Training on Stroop Performance in Older Adults. *Journal of Aging Research, 2012*, 7.

Polich, J., & Lardon, M. T. (1997). P300 and long-term physical exercise *Electroencephalogram Clinical Neurophysiology, 103*, 493-498.
Predovan, D., Fraser, S. A., Renaud, M., & Bherer, L. (2012). The Effect of Three Months of Aerobic Training on Stroop Performance in Older Adults. *Journal of Aging Research*, 7. doi:10.1155/2012/269815
Ratey, J. J., & Loehr, J. E. (2011). The Positive impact of physical activity on cognition during adulthood: a review of underlying mechanisms, evidence, and recomendations. *Reviews in the Neurosciences, 22*(2), 171-185.
Schubert, T. W., Murteira, C., Collins, E. C., & Lopes, D. (2013). A Software Library for Collecting Response Latencies in Online Studies of Cognition. *PLOS ONE, 8*(6). Retrieved from http://www.plosone.org website:
Skitka, L. J., & Sargis, E. G. (2006). The Internet as Psychological Laboratory. *Annual Review of Psychology*(57), 529-555. doi: 10.1146/annurev.psych.57.102904.190048
Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*(18), 643-662.
Tam, N. D. (2013). Improvement of Processing Speed in Executive Function Immediately following an Increase in Cardiovascular Activity. *Cardiovascular Psychiatry and Neurology, 2013*, 6.
Vasques, P. E., Moraes, H., Silveira, H., Deslandes, A. C., & Laks, J. (2011). Acute exercise improves cognition in the depressed elderly: the effect of dual-tasks. *Clinics, 66*(9), 1553-1557.